



Owens (Dry) Lake, California: A Human-Induced Dust Problem

by
Marith C. Reheis
U.S. Geological Survey

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Populations are growing rapidly in large parts of the semi-arid to arid regions of the southwestern United States. As a result, stresses are increasing on fragile desert surfaces and on water supplies in an area where water is a precious commodity. Nearly all of the available surface water has already been claimed and diverted for human use, and ground water is now tapped for new water supplies. As surface and ground water diversion increases, arid-land surfaces that were previously wet or stabilized by vegetation are increasingly susceptible to deflation by wind, resulting in desertification and dust storms. One spectacular example of such an effect is Owens (dry) Lake in east-central California (**fig. 1**). The following summarizes the adverse effects of the desiccation of Owens Lake and sketches some of the research being conducted on these effects.

The Owens (dry) Lake dust problem

Owens (dry) Lake (**fig. 1**) was a perennial lake at the terminus of the Owens River throughout historic time; the lake held water continuously, and at times overflowed to the south, for at least the last 800,000 years (Smith et al., 1997). During the late 1800's and early 1900's the lake fluctuated between about 7-15 m deep and had an area of about 280 km², depending on drought conditions and irrigation diversions; the irrigation withdrawals were large enough to desiccate the lake eventually (St. Amand et al., 1986). Steamboats hauled ore across the lake from mines in the Inyo Range (**fig. 1**). Water was first diverted from the Owens River to the City of Los Angeles in 1913, and by 1926 Owens Lake was dry.

The dry bed of Owens Lake has produced enormous amounts of windblown dust since the desiccation of the lake (**fig. 2**). The term "Keeler fog" (for the town on the east side of the lake, **figs. 1 and 2b**) was coined locally decades ago for the pervasive, unusually fine-grained, alkaline dust that infiltrates the smallest cracks and contaminates residences. The lake bed is probably the largest single source of PM₁₀ dust (aerosol particles smaller than 10 microns in aerodynamic diameter) in the United States; by one estimate, 900,000-8,000,000 metric tons per year (Gill and Gillette, 1991). Assuming a lake-bed area of 280 km² and a density of 1.5-2.0 g/cm³ for lake sediment, erosion of this amount of dust would lower the lake bed by 0.2-1.5 centimeters per year. PM₁₀ dust is regulated by California and the United States because these dust particles are so small that they can be inhaled deeply into the human respiratory tract to create a health hazard. As reported in the Los Angeles Times (12/17/96): "One day last year in Keeler, particles surged to a nationwide record that was 23 times greater than a federal health standard allows. Keeler residents are exposed to unhealthful levels 25 days a year. In Ridgecrest, 60 miles south of the lake (dark area northeast of China Lake in **fig. 2a**), that situation occurs 10 days a year, according to the Great Basin air agency. 'When

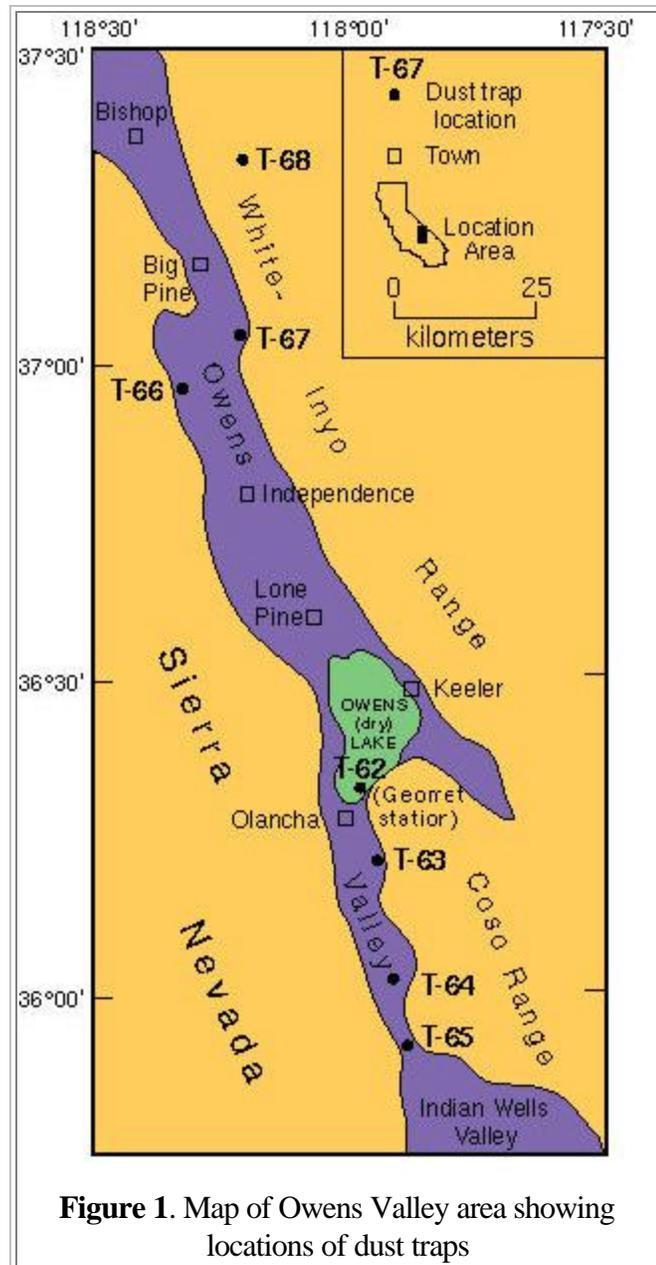


Figure 1. Map of Owens Valley area showing locations of dust traps

we see the white cloud headed down through the pass, the ER and doctors' offices fill up with people who suddenly got worse. It's a pretty straightforward cause and effect,' said Dr. Bruce Parker, an emergency physician at Ridgecrest Community Hospital." An additional health concern is inhalation of trace metals in the dust. The lake bed has a mean arsenic concentration of 50 ppm, and has as much as 150 ppm in the north and east (reported in Reid et al., 1994). Aerosols sampled from Owens dust storms commonly contains significant amounts of arsenic concentrated in the <10 micron fraction. Arsenic levels can be as high as 400 ng/m³ in air samples (Reid et al., 1994) and 10-50 ppm in samples from dust traps in Owens Valley (**fig. 1**).

In addition to health problems, Owens (dry) Lake dust affects visibility in many nearby areas, including three national parks (Sequoia, Kings Canyon, and Death Valley) and several national forests and wilderness areas. For example, dust plumes have been tracked to elevations of over 3,000 meters in the Ancient Bristlecone Pine Forest in the White Mountains (**fig. 1**), 100 kilometers north of Owens Lake, and reports of dust-covered vegetation in the White-Inyo Range are common (Gill, 1996). Owens dust storms regularly cause suspension of operations at China Lake Naval Weapons Center (near China Lake, **fig. 2a**) resulting in millions of dollars in economic losses.

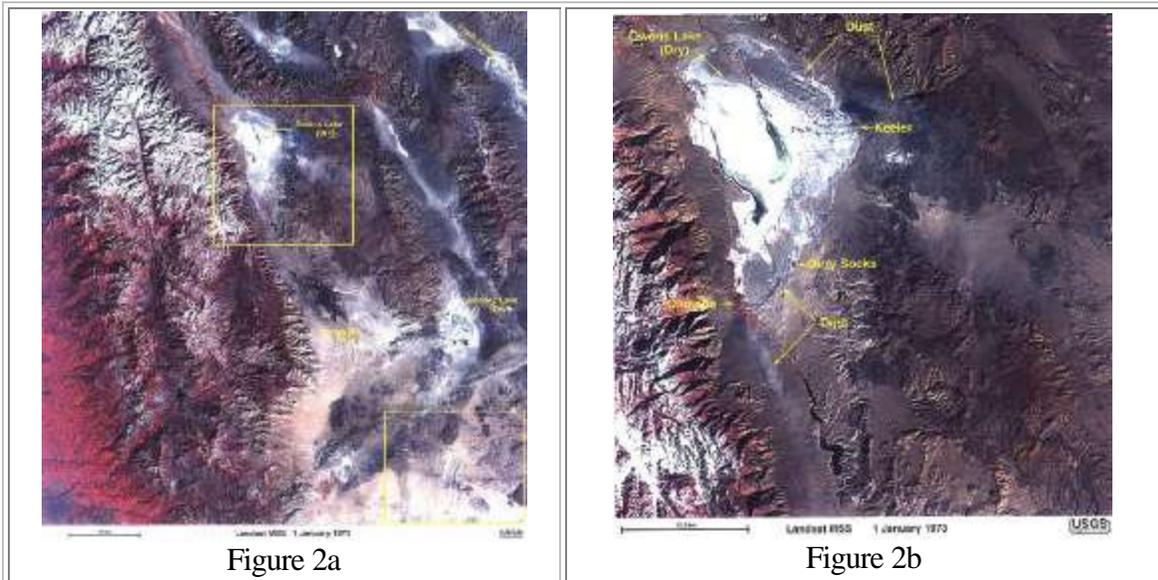




Figure 2. Dust storms in Owens Valley. **A**, Landsat MSS image of dust clouds in the region east of the southern Sierra Nevada, January 1, 1973. Yellow squares show enlarged areas of figures 2B and 2C. **B**, two dust plumes originating from Owens (dry) Lake. The southern plume is moving south past Olancha; the northern plume is moving southeast over Keeler. **C**, dust plumes streaming south from the area of Cuddeback (dry) Lake; note that many of the individual plumes are being emitted from alluvium rather than from the playa (Reheis and Kihl, 1995). Images courtesy of P. Chavez, U.S.G.S.. **D**, view from 15 km southeast of Keeler (**fig. 1**) looking northwest across Owens (dry) Lake. Sierra Nevada in background is nearly obscured by the dust cloud.

Because the dust storms from Owens (dry) Lake violate EPA standards, Los Angeles is required to mitigate the dust emissions by the year 2001. The Great Basin Unified Air Pollution Control District, the local arm of the EPA, released its report on mitigation plans in December; its preferred alternative would cost Los Angeles \$70 million in construction costs and \$25 million in annual maintenance. This report and Los Angeles' reaction to it have generated nationwide news coverage and discussion of the issues.

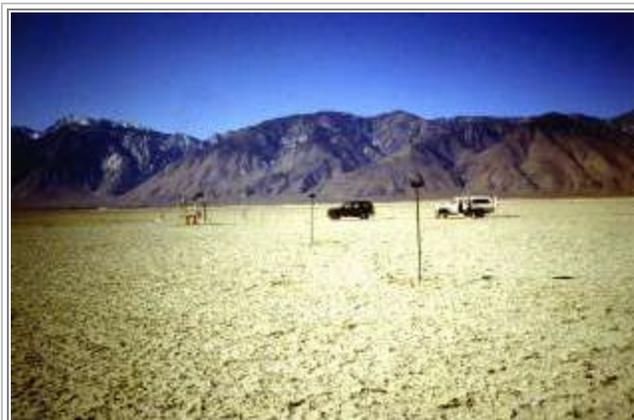


Figure 3. Photograph of Geomet station and dust traps at south end of Owens (dry) Lake

Studies of dust storms in Owens Valley

Studies of Owens (dry) Lake and its dust storms began in the early 1980's and have been funded by the State of California, the China Lake Naval Weapons Center, NOAA, EPA, and the USGS, among other agencies. These studies have included (1) long-term monitoring of ambient aerosols (Barone et al., 1991; Cahill et al., 1994), (2) intensive measurements of individual storms at sites around the lake bed

(Reid et al., 1994; Cahill et al., 1996; Gillette et al., in press a, b), (3) hourly monitoring since 1992 of weather, sand movement, and surface conditions at the Geomet site on the south end of the lake bed (**figs. 1 and 3**), (4) satellite and airborne observations of dust storms (**fig. 2b**; St. Amand et al., 1986), (5) detailed sampling and analysis of lake-bed crusts and subsurface deposits (WESTEC, 1984; St. Amand et al., 1986; Cahill et al., 1996), and (6) measurement of dust composition and deposition rates on and downwind of the lake bed since 1991 (Reheis, in press). In addition, the Great Basin Unified Air Pollution Control District has conducted extensive studies related to stabilizing the lake bed.

Why does Owens (dry) Lake produce so much dust compared to other playas in southern California and Nevada (typically 10-100 times more; Reheis, in press)? The dry lake bed is often wet during the cool months and is underlain by a large brine pool that saturates the sediments at shallow depths; as a result, the surface is commonly crusted, especially during the late winter and early spring, with salt (chiefly sodium sulfates and sodium carbonates; St. Amand et al., 1986) that is extremely vulnerable to erosion by saltating particles during the frequent high winds in the Owens Valley (Cahill et al., 1996).

Salt-rich dust derived from Owens (dry) Lake travels both north and south on turbulent winds that are funneled through Owens Valley by the adjacent Sierra Nevada on the west and the White-Inyo Range and Coso Range on the east (**figs. 1 and 2a**). This dust can be transported long distances because it is unusually fine-grained compared to dust from other natural sources (Cahill et al., 1994, p. 6-7); dust plumes from the playa (**fig. 2**) have been tracked by satellite to distances of 250 km to the south into the area of Los Angeles (Saint Amand et al., 1986). A recent report on patterns of dust transport to the Grand Canyon (Vasconcelos et al., 1996) notes that high dust concentrations are most common in air masses arriving from the southwest, i.e. from southern California. Though the authors suggest this dust is generated from agriculture and suburban development, it is possible that fine-grained dust from Owens (dry) Lake may contribute significantly to the dust load in regions to the east.

Dust deposition rates and potential effects on soils

The infiltration of salt-rich dust from Owens (dry) Lake into soils around the playa likely has affected vegetation and soils, which are mostly not adapted to saline conditions because the lake held water continuously for at least the past 800,000 years and probably throughout much of the Quaternary (Smith et al., 1997). The USGS has maintained seven dust traps within Owens Valley (**fig. 1**), sampled twice a year since November 1991, to provide data on the amount and composition of dust that is likely to be incorporated into the soils. "Winter" samples accumulate from October through April, a period that typically includes the largest and most frequent dust storms of the spring and fall (Cahill et al., 1996). "Summer" samples accumulate from May through September; the playa crust tends to be more stable during this period than in the winter, although large dust storms may still occur. Annual dust-deposition rates ("dust flux") measured in Owens Valley can be compared to a data base of modern dust flux and composition measured since 1984 at many sites in southern Nevada and California (Reheis and Kihl, 1995);

these sites are in relatively undisturbed areas compared to the area around Owens Lake playa.

The content of fine particles and salt (**fig. 4**) in Owens Valley dust samples is very high, especially near the lake bed. The <10 micron content is commonly 60-90 % in samples from site T-62 on the south side of the lake bed (**fig. 1**) and ranges from 25 to 70 % at the other sites. Clay content (<2 micron) of samples from site T-62 ranges from about 20 to 50 %, and contents of samples from the other sites range from about 10 to 30 %. The fine particle size of the dust-trap samples is similar to measurements of samples from within dust plumes (Gearhart et al., 1995; Cahill et al., 1994), and this size distribution permits long transport distances of the dust (Tsoar and Pye, 1987). The soluble salt content of dust deposited around Owens (dry) Lake ranges from about 15 to 35 % (Reheis, in press). The salt content of most of the samples near and south of the playa is higher than that of the regional dust (**fig. 4a**; Reheis and Kihl, 1995).

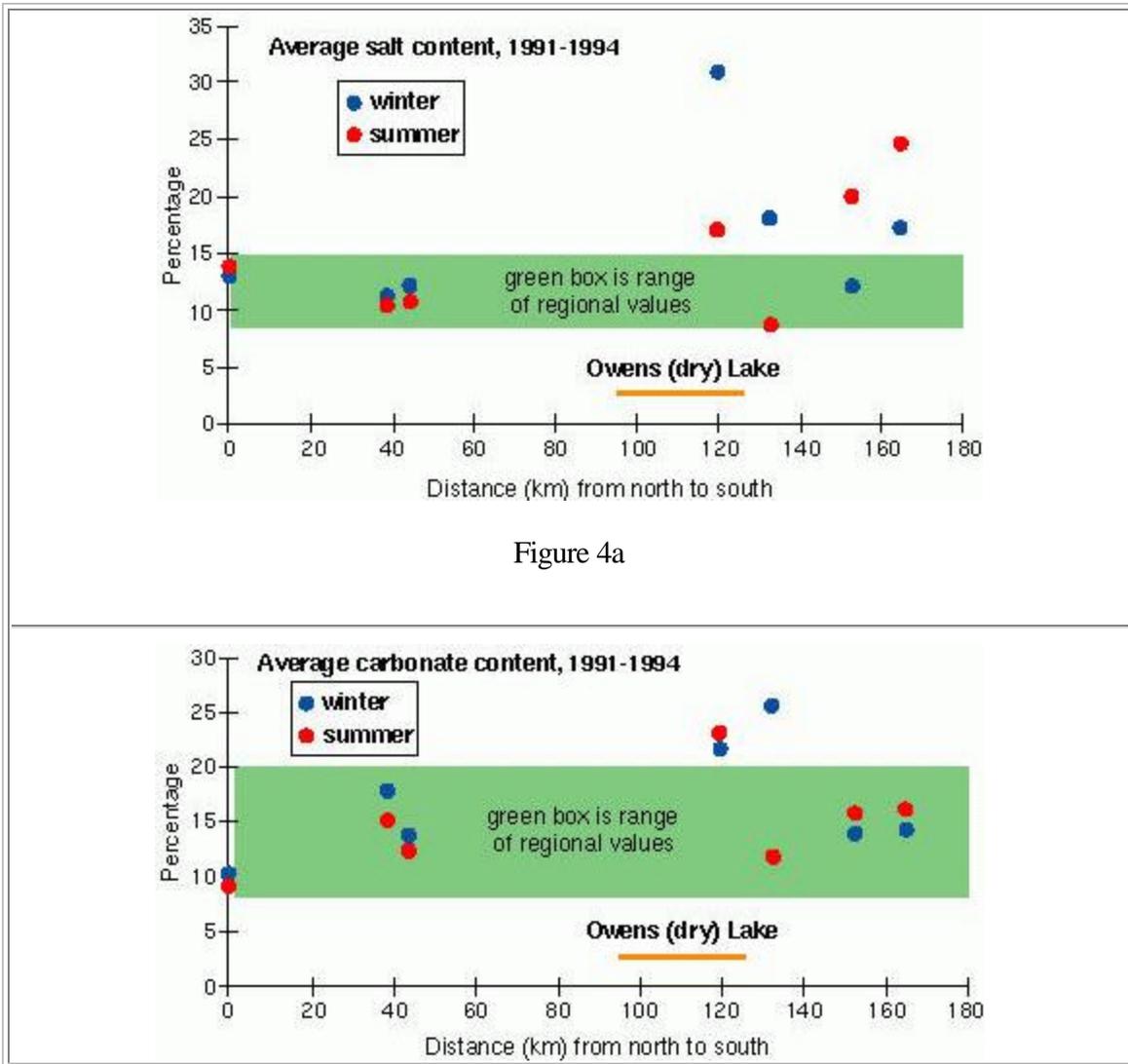


Figure 4a

Figure 4b

Figure 4. Average contents of dust samples by season along a north-south transect in Owens Valley. Box (range of regional values) encloses mean and one standard deviation (individual points not plotted) of dust samples from 50 other sites in southern Nevada and California (data of Reheis and Kihl, 1995). Positions of dust traps are projected to an imaginary line parallel to the valley axis.

Dust flux is strongly related to proximity to the Owens Lake playa and to season. Daily fluxes of salt, carbonate, and silt-plus-clay are highest at site T-62 on the south end of the playa and decrease both to the north and south (**fig. 5**). The decrease is most obvious to the south because the site locations there provide a better longitudinal transect (**fig. 1**). These relations clearly show that the playa is the dominant source of salt, carbonate, and fine mineral grains in the dust samples and are consistent with results of a filter-collected dust-sampling program conducted over 17 weeks in 1979 (Barone et al., 1981) between Bishop and site T-65 (**fig. 1**). Seasonal contrasts are sharp and most dramatic near the playa. At most sites, fluxes are significantly higher in winter than in summer.

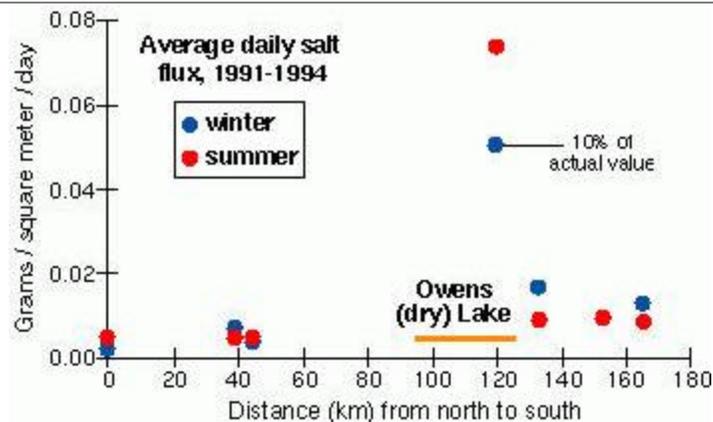


Figure 5a

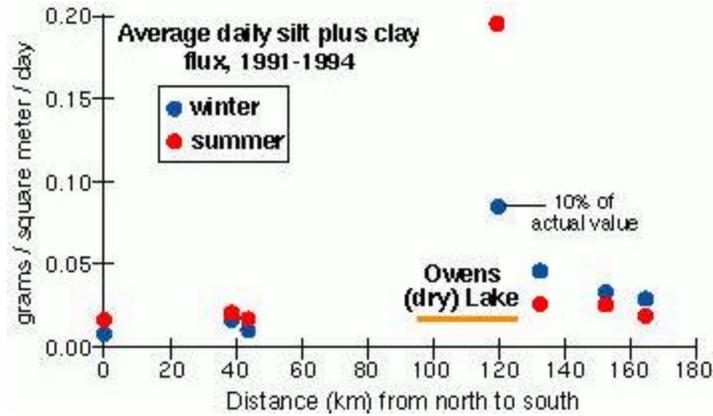


Figure 5b

Figure 5. Average daily dust fluxes by season along a north-south transect in Owens Valley. Note that winter fluxes of salt and silt plus clay at site T-62 on the playa are plotted at 10 % of their actual values. Positions of dust traps are projected to an imaginary line parallel to the valley axis.

On and adjacent to Owens (dry) Lake, inter-annual fluxes of dust and soluble salt are consistently one to two orders of magnitude higher than fluxes at similar latitudes elsewhere in eastern California and southern Nevada (**fig. 6**; data of Reheis and Kihl, 1995). The ranges of regional rates shown in figure 6 represent the mean and one standard deviation of five years at 50 sites in southern Nevada and southeastern California (locations shown in **fig. 7**). To a distance of at least 40 km south of the playa, annual salt fluxes in two out of the three years are significantly higher than the average regional rates.

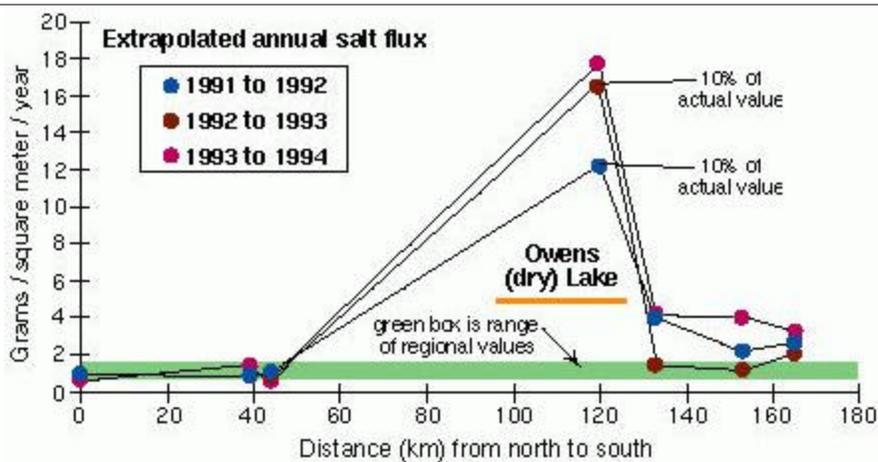


Figure 6a

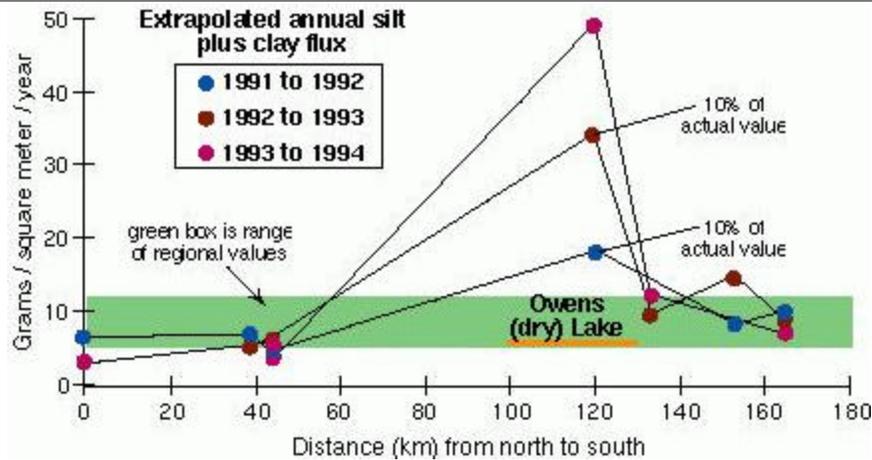


Figure 6b

Figure 6. Annual salt and silt-plus-clay flux in Owens Valley, extrapolated from daily flux values. Box (range of regional values) encloses mean and one standard deviation (individual points not plotted) of dust samples from 50 other sites in southern Nevada and California (data of Reheis and Kihl, 1995). Note that total dust and salt fluxes at site T-62 on the playa in 1991-1992 and 1992-1993 are plotted at 10 % of their actual values. Lines connecting points are intended only to guide the eye. Positions of dust traps are projected to an imaginary line parallel to the valley axis.

It may appear that the influence of the playa does not extend to Indian Wells Valley (**fig. 1**) because the measured amount of dust at site T-65 approaches regional dust-flux amounts (**fig. 6**). However, the distant sites (including those to the north) may still receive significant amounts of dust from the Owens Lake playa because of the long-distance transport of the fine playa dust. Deposition rates prior to the desiccation of the lake are unknown. Marchand (1970) showed that as much as 50 % of the silt fraction of soils at high elevations in the White Mountains consisted of eolian dust, probably derived from Owens Valley and exposed sediment of Pleistocene Lake Owens over thousands of years, and modern storms originating on the Owens Lake playa have deposited measurable amounts of dust on the Ancient Bristlecone Pine Forest in the White Mountains (Gill, 1996). The <10 micron fraction of the dust from the playa ranges from about 50 to 90 %; Tsoar and Pye (1987) show that dust of this size can be transported more than a thousand kilometers even by light storms. It seems probable that much of the dust generated by Owens Lake playa is transported far away from the valley and the sites monitored in this project.

Estimates of the amount of dust actually infiltrated into the soils, and studies of the effect of salt-rich dust on natural vegetation in Owens Valley, have not been made. Although the dust deposition recorded by the traps may not accurately reflect the amount of dust added to the soils, modern dust fluxes measured by the same type of dust trap used in this study are similar to accumulation rates of silt, clay, and carbonate in Holocene soils elsewhere in southern Nevada and California (Reheis et al., 1995). It is likely that the soluble-salt component of dust is more efficiently moved downward into the soils because it is more easily dissolved by the infrequent rains in this desert area, and salts comprise a disproportionate amount of Owens Lake playa dust. It would be strange indeed if soluble salts are not increasing in the soils around the playa, resulting in increased soil pH and potentially affecting plant communities. The WESTEC Services Inc. (1984) report determined that dust delayed the rate of recolonization of the outer edge of the playa by vegetation. In Nevada, Young and Evans (1986) showed that long-term deposition of playa dust has resulted in the extension of salt-tolerant plant communities into areas which should otherwise support sagebrush-dominated plant communities.

Farmer (1993) summarized results from studies of vegetation downwind of limestone quarries, cement plants, and a few other dust sources such as roads and coal quarries to show that excessive levels of dust can affect photosynthesis, respiration, transpiration, and generally cause reduced productivity and changes in community structure (the species of plants present).

Summary

The artificial desiccation of Owens Lake has created the single largest source of PM-10 dust in the United States. Dust storms from the dry lake bed are a significant health hazard to residents of Owens Valley and nearby areas, and impact air quality in a large region around the lake bed. Salt-rich dust derived from the Owens Lake playa is deposited in significant quantities, much larger than those elsewhere in southern Nevada and California, to distances of at least 40 km north and south of the playa. The dust-flux measurements indicate that significant quantities of salt-rich dust are probably being added to the soils in the region around Owens Lake playa, which may affect soil pH and vegetation. Owens Lake is an extreme example of the potentially destabilizing effect on

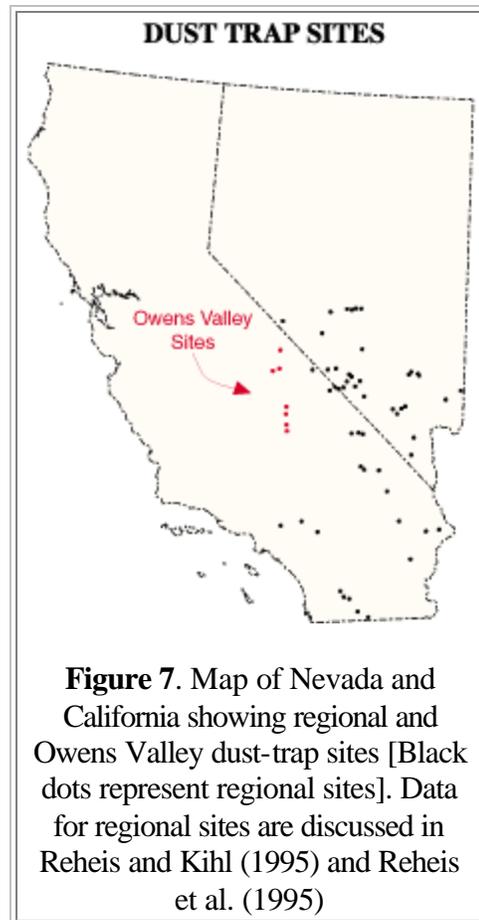


Figure 7. Map of Nevada and California showing regional and Owens Valley dust-trap sites [Black dots represent regional sites]. Data for regional sites are discussed in Reheis and Kihl (1995) and Reheis et al. (1995)

land surfaces and vegetation by the extraction of surface and ground water in desert regions.

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